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Development and calibration of an engineering model for simulation of wake velocity deficits

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Development and calibration of an engineering model for simulation of wake velocity deficits

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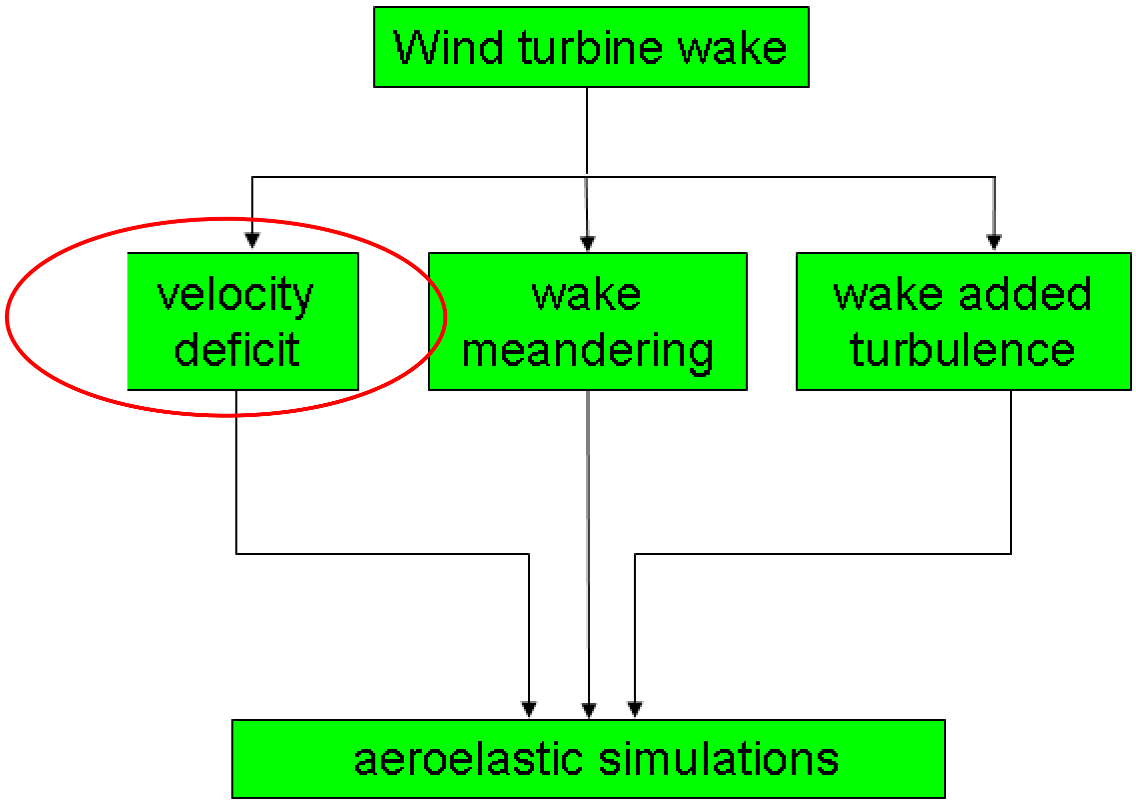
Background – The Dynamic Wake Meandering (DWM) Model

DWM model



Model description – DWM model

Three model parts

1) *Wake deficit generation and development*
2) *Wake meandering*
3) *Generation of wake added turbulence*

and

fully integrated in the aeroelastic code HAWC2

- just specify positions of wake generating turbines -

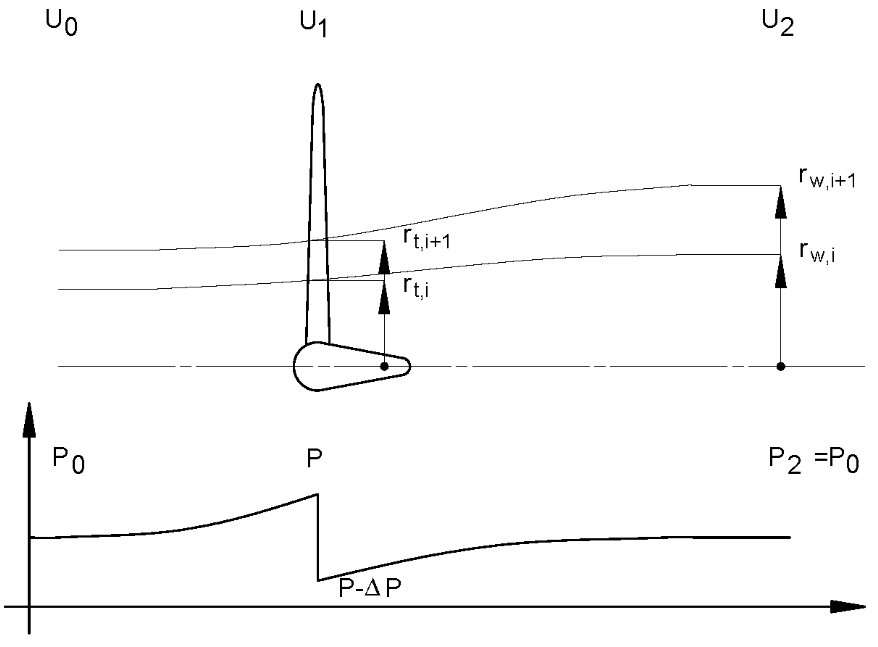
Aagaard Madsen, H.; Larsen, G.C.; Larsen, T.J.; Mikkelsen, R.; Troldborg, N., Wake deficit-and turbulence simulated with two models compared with inflow measurements on a 2MW turbine in wake conditions. In: Scientific proceedings. 2008 European Wind Energy Conference and Exhibition, Brussels (BE), 31 Mar - 3 Apr 2008. (2008) p. 48-53

Approach for generation of initial velocity deficit and its development downstream

1. Generation of initial deficit from BEM induction in far wake combined with continuity in stream tubes
2. A boundary layer equation model (BLE) is used for developing initial velocity profiles as function of downstream position under influence of self generated turbulence viscosity and from contribution from ambient turbulence

Model description
1) Generation of initial velocity deficit

Derived from the BEM induction



initial velocity $u_2(r_{w,i})$

$$r_{w,i+1} = \sqrt{\frac{1-a_i}{1-2a_i}(r_{t,i+1}^2 - r_{t,i}^2) + r_{w,i}^2}$$

Model description
2) Velocity deficit development

Based on a numerical implementation of the thin shear layer approximation of the Navier-Stokes equations – axis-symmetric - with initial conditions obtained from BEM

$$U\frac{\partial U}{\partial x}+V\frac{\partial U}{\partial r}=\left(\frac{\upsilon_T}{r}\right)\frac{\partial}{\partial r}\left(r\frac{\partial U}{\partial r}\right)$$

$$\upsilon_T = k_2 b\left(U_0 - U_c\right)+\upsilon_{TA}$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left(rV\right)+\frac{\partial U}{\partial x}=0$$

$$\upsilon_{TA} = k_1 Ti$$

Model description
- influence of ambient turbulence

Ainsley

$$\varepsilon_{tot} = k_2 b\left(U_0 - U_c\right) + \frac{\kappa}{\ln\left(z_H / z_{0)}\right)}$$

can be rewritten to:

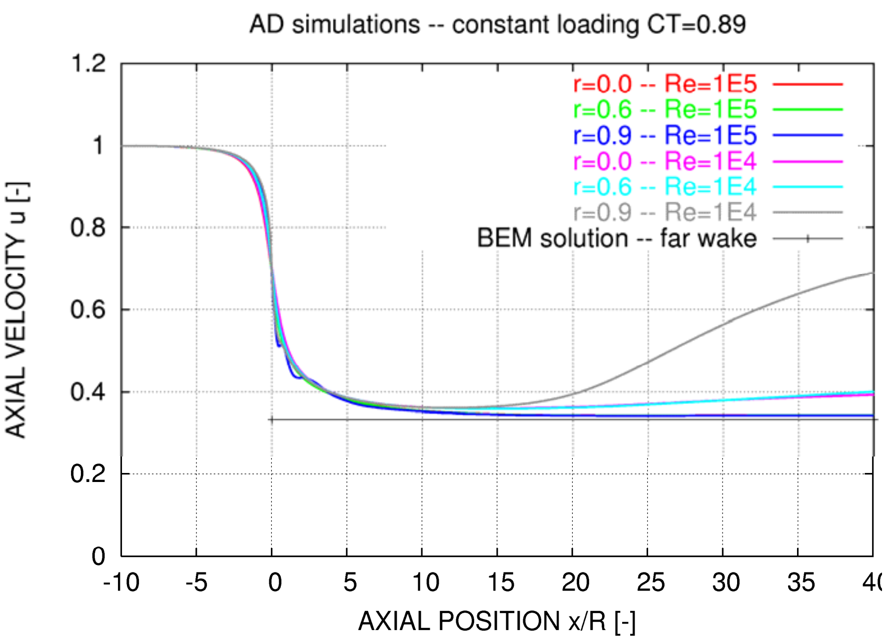
$$\varepsilon_{tot} = k_2 b\left(U_0 - U_c\right) + \frac{TI\left(z\right)}{\alpha}$$

with $\alpha = 2.4$

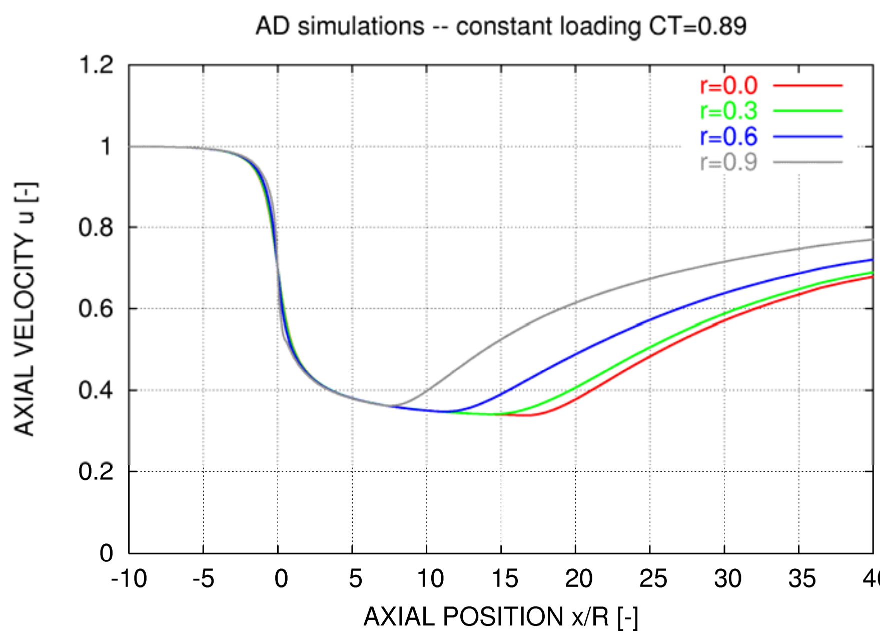
Actuator disc (AD) simulations used for calibration of the BLE model

LAMINAR FLOW

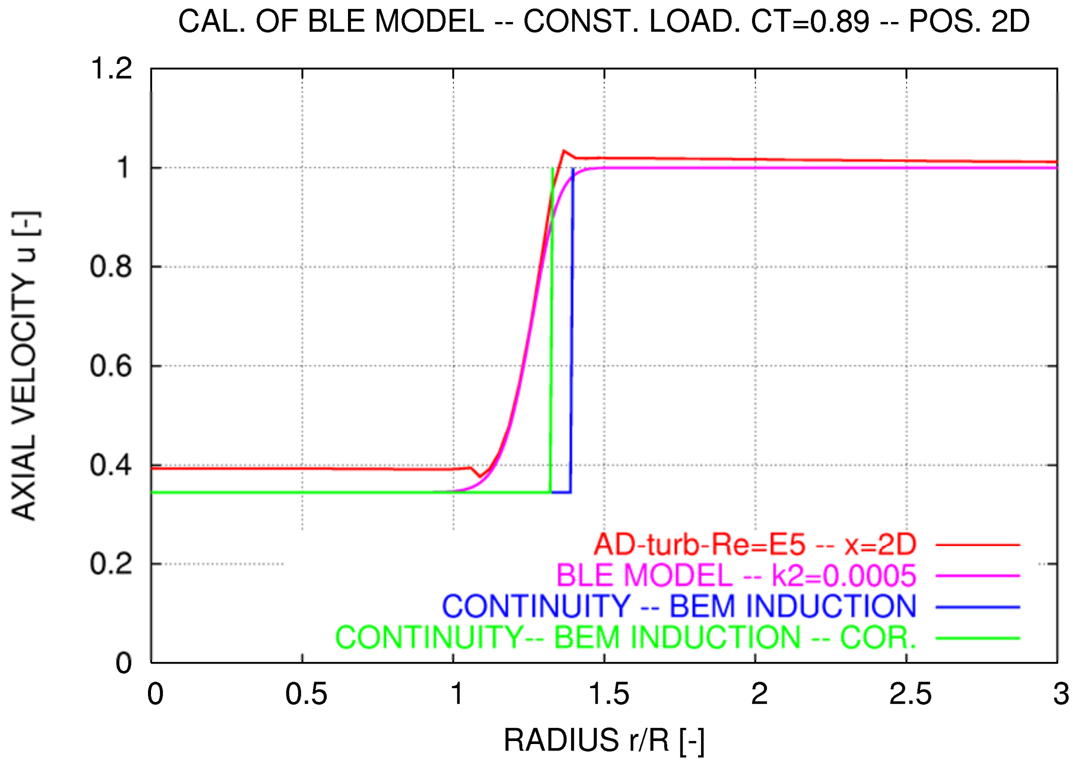
- influence of Re. no.



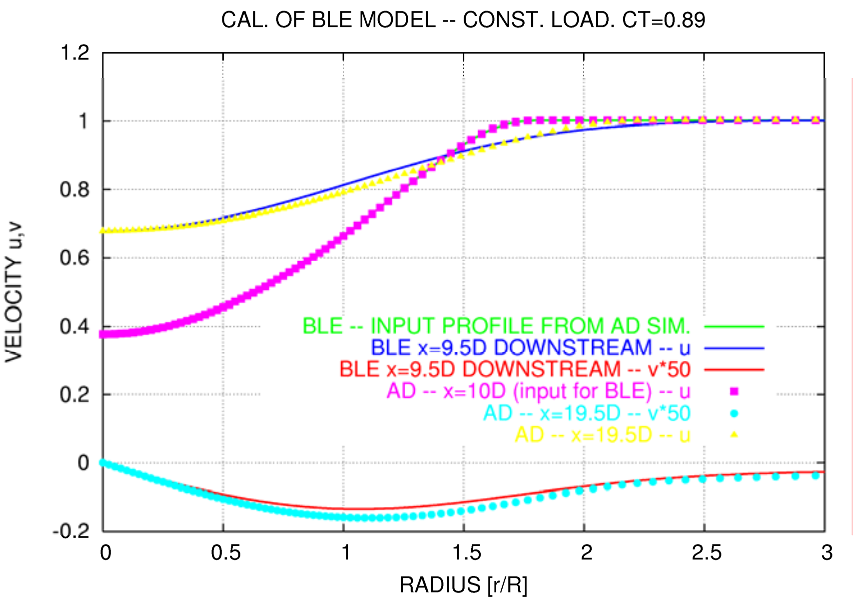
TURBULENT FLOW

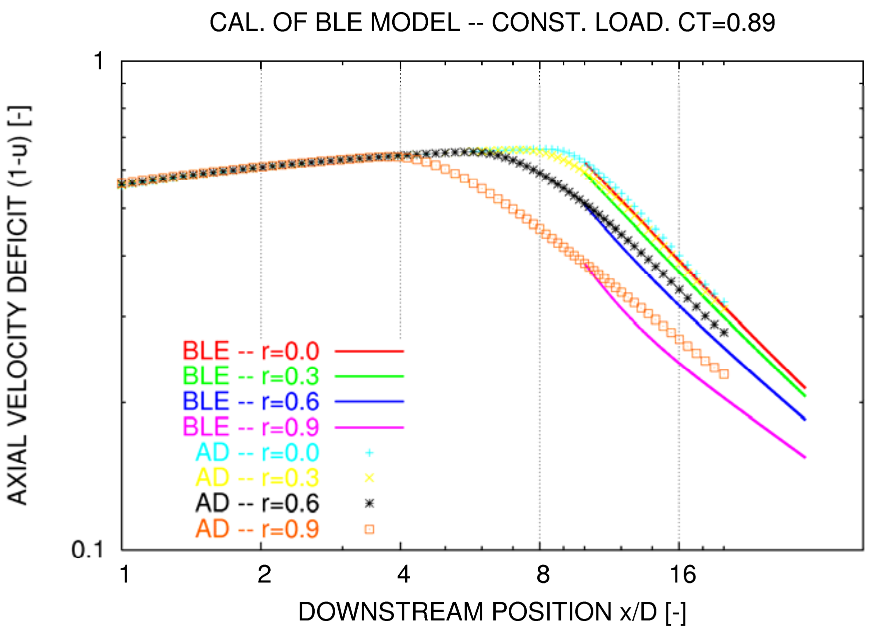


Calibration of initial deficit and k2 in the near wake region – 2D

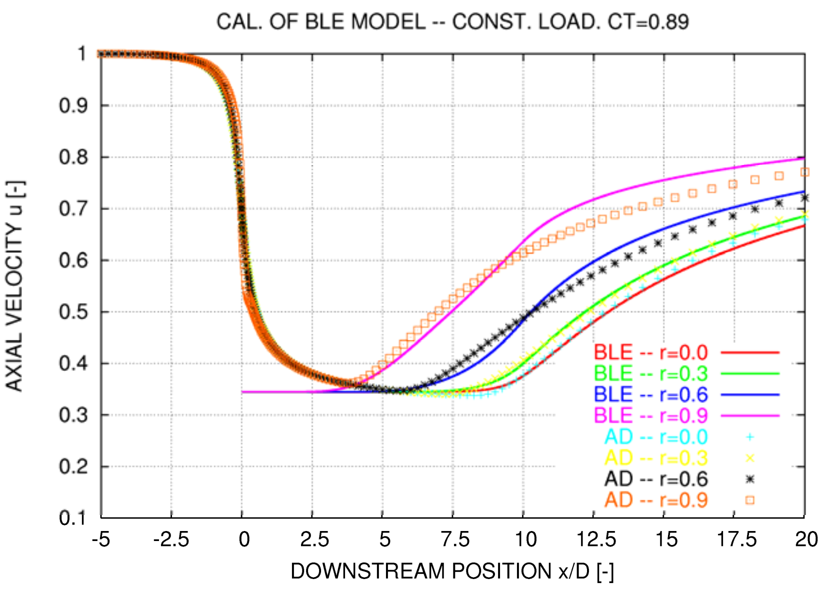


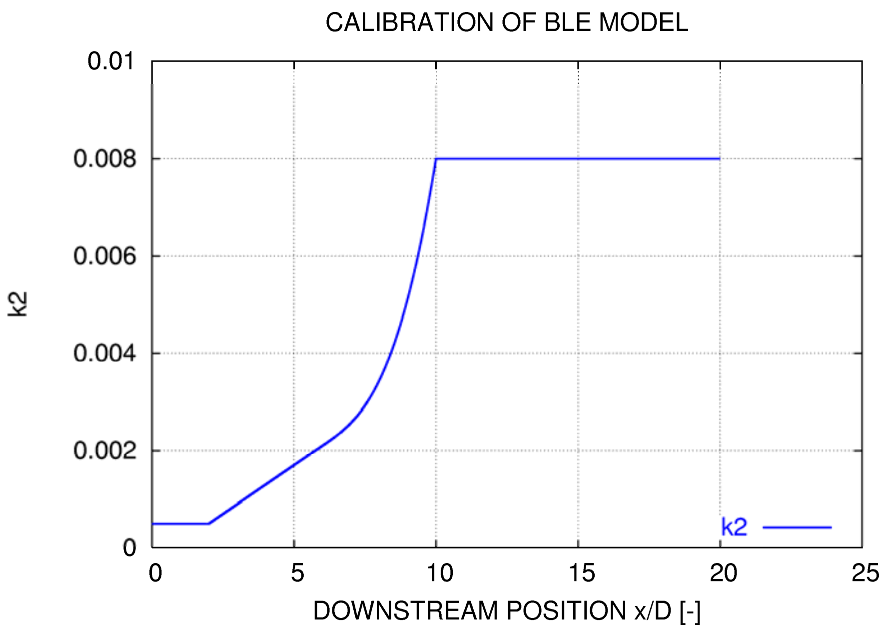
Calibration of k2 in the far wake from 10D downstream





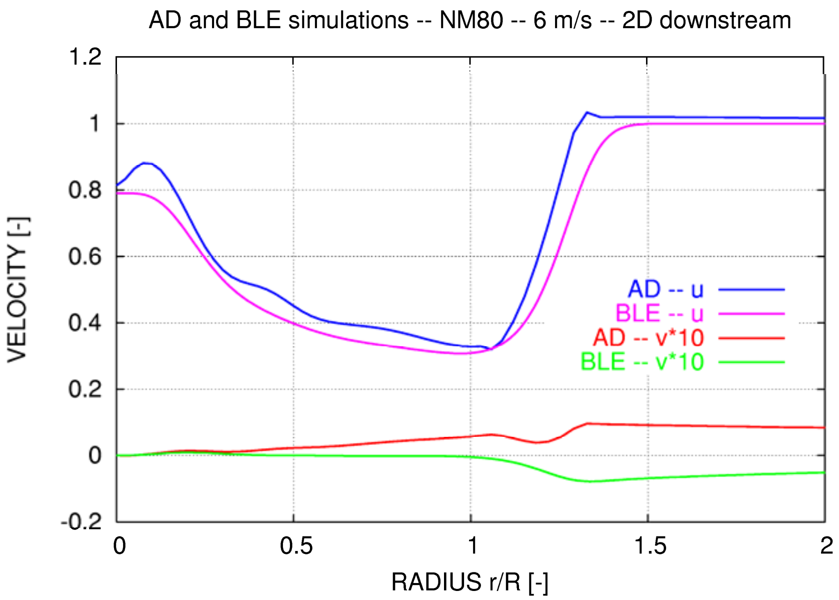
Calibration of k2 in the intermediate wake region



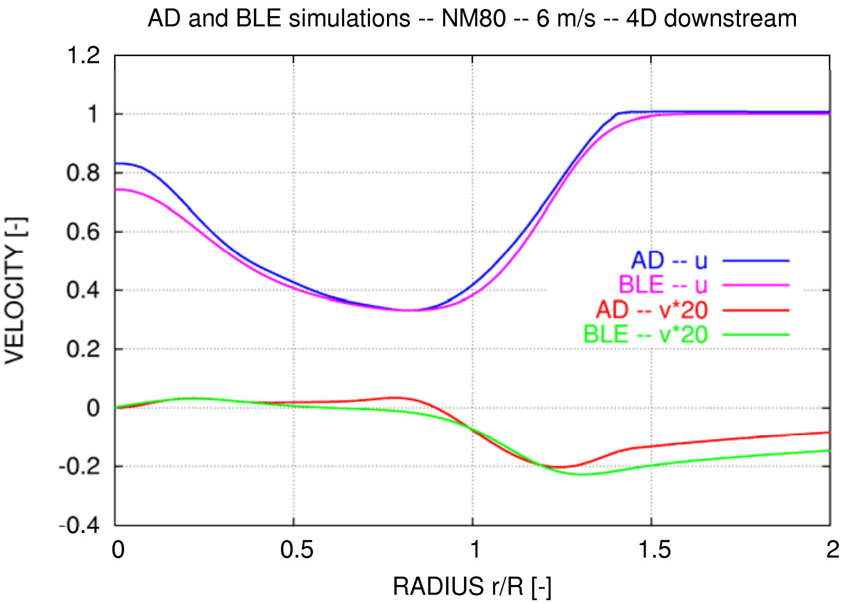


Use of the BLE model on the NM80 rotor. Comparison of the BLE model with AD results

2D downstream

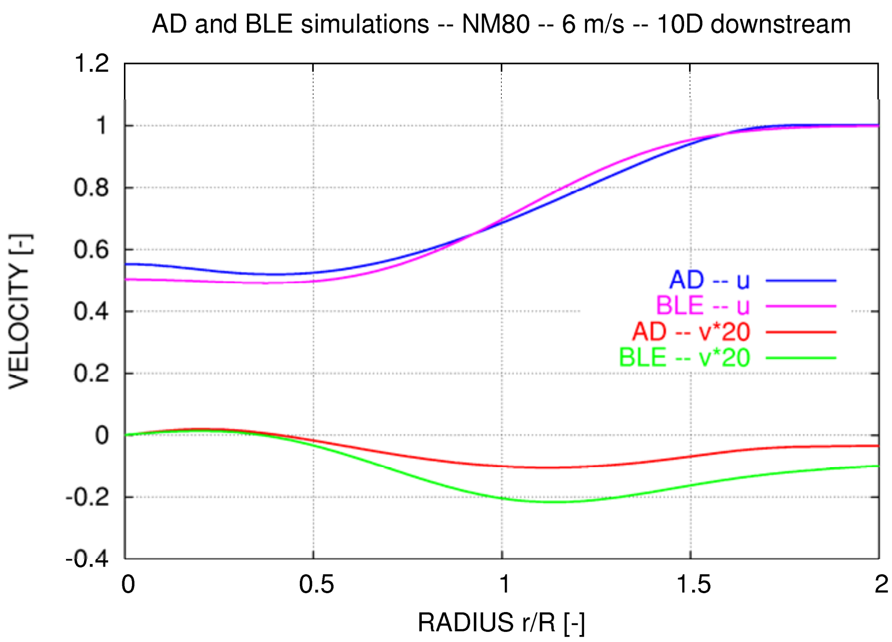


4D downstream

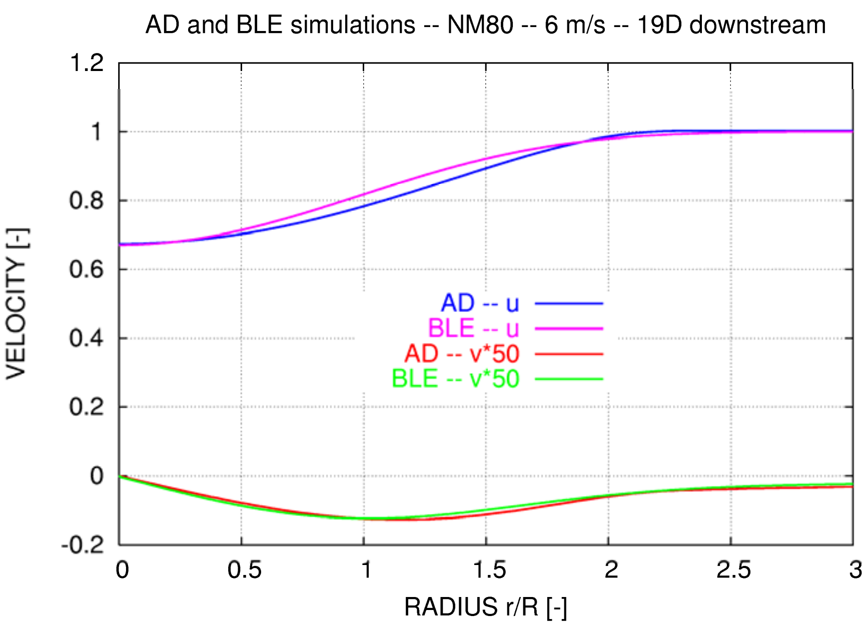


Use of the BLE model on the NM80 rotor. Comparison of the BLE model with AD results

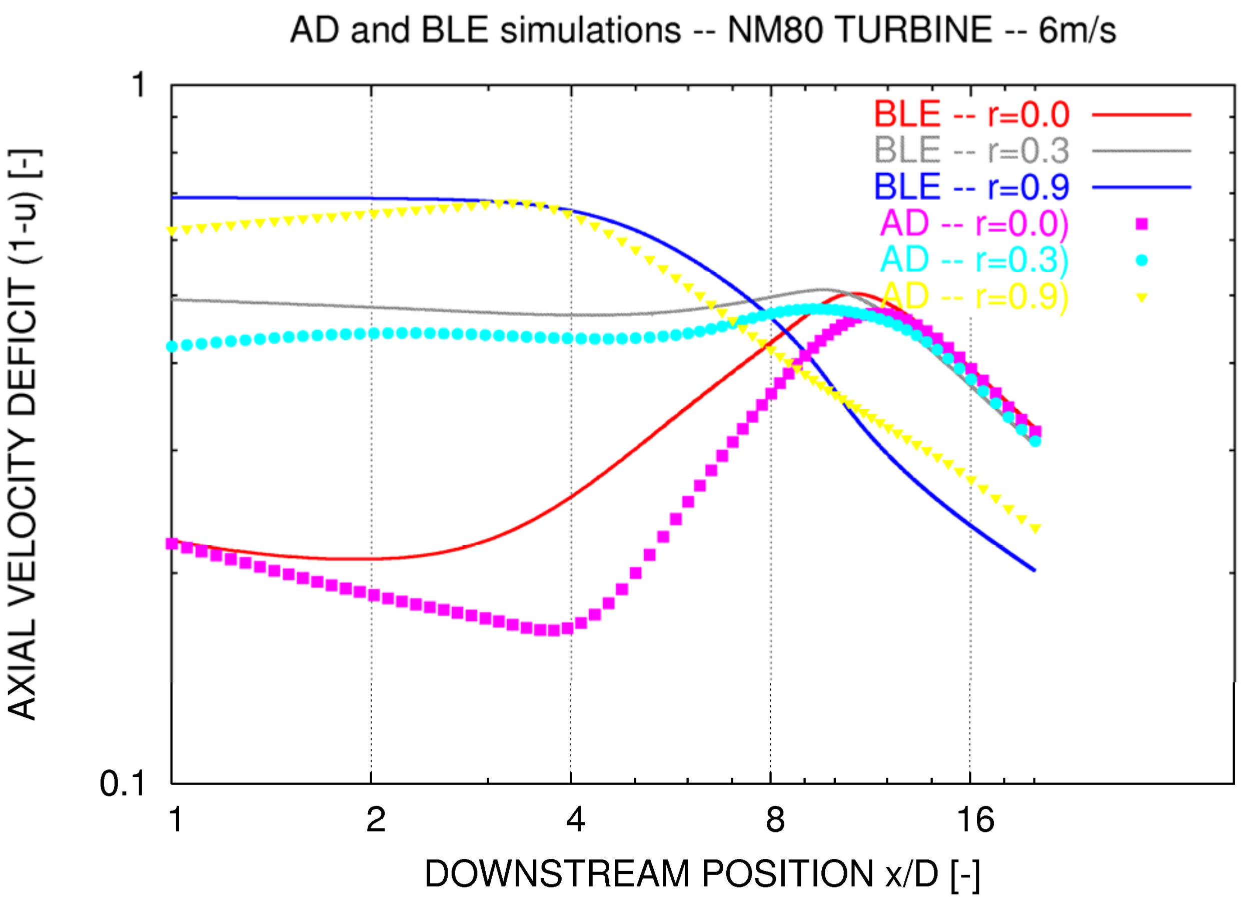
10D downstream



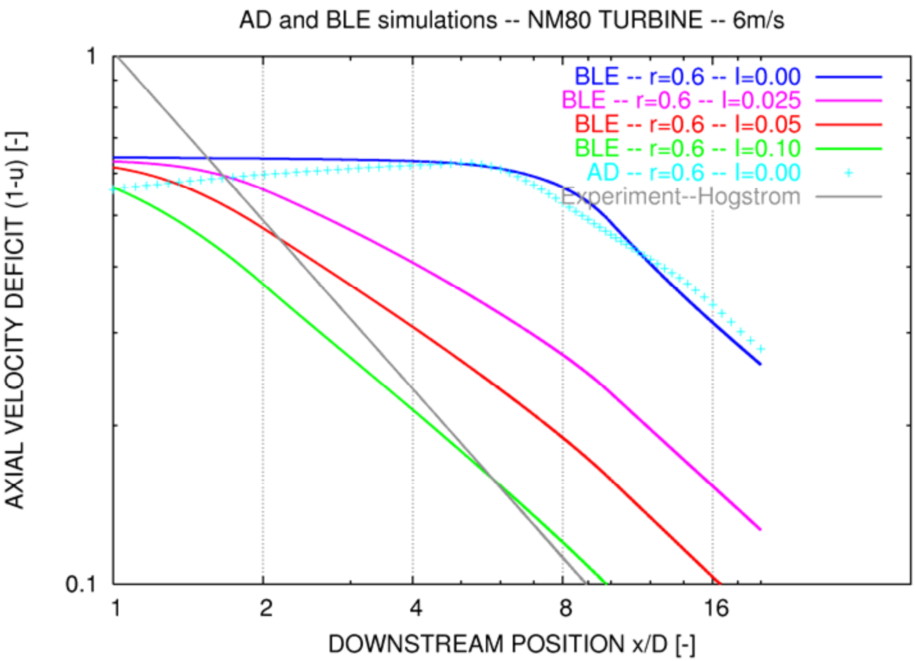
19D downstream



Use of the BLE model on the NM80 rotor. Comparison of the BLE model with AD results



Influence of ambient turbulence



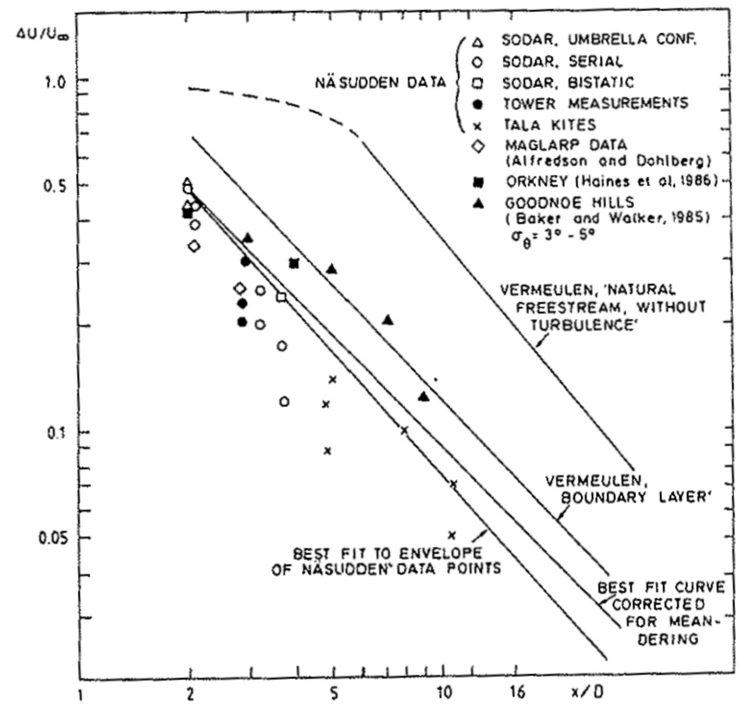
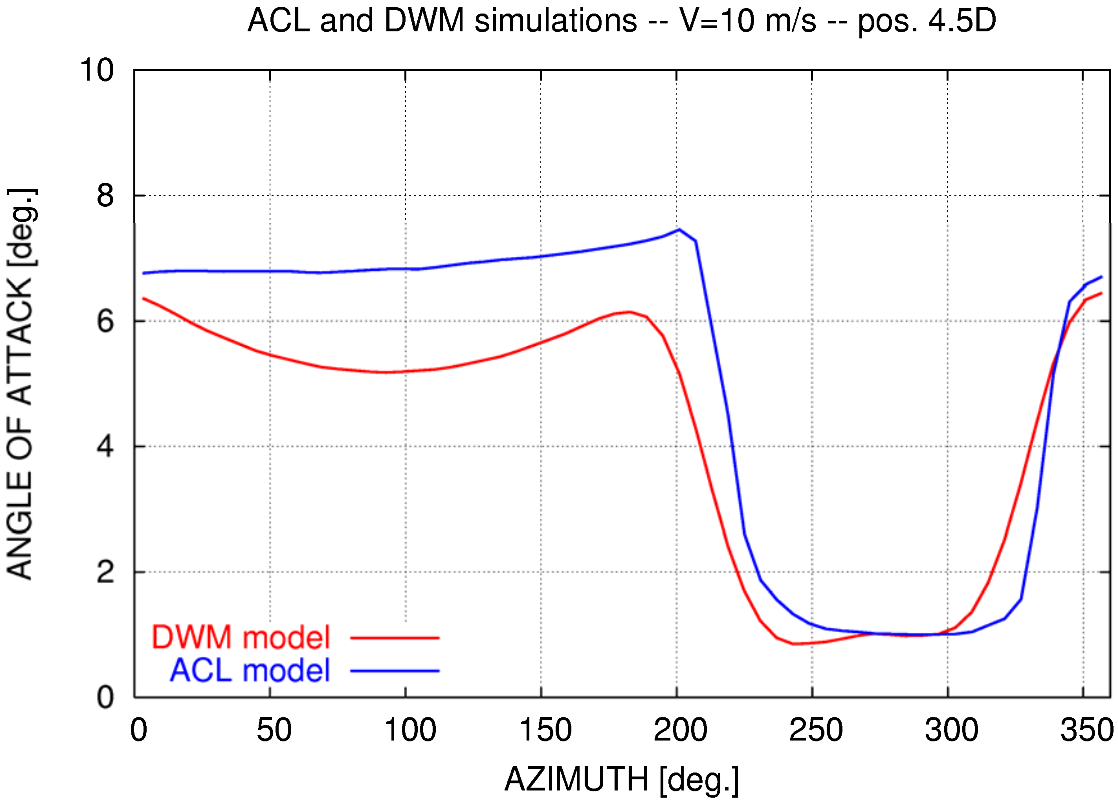


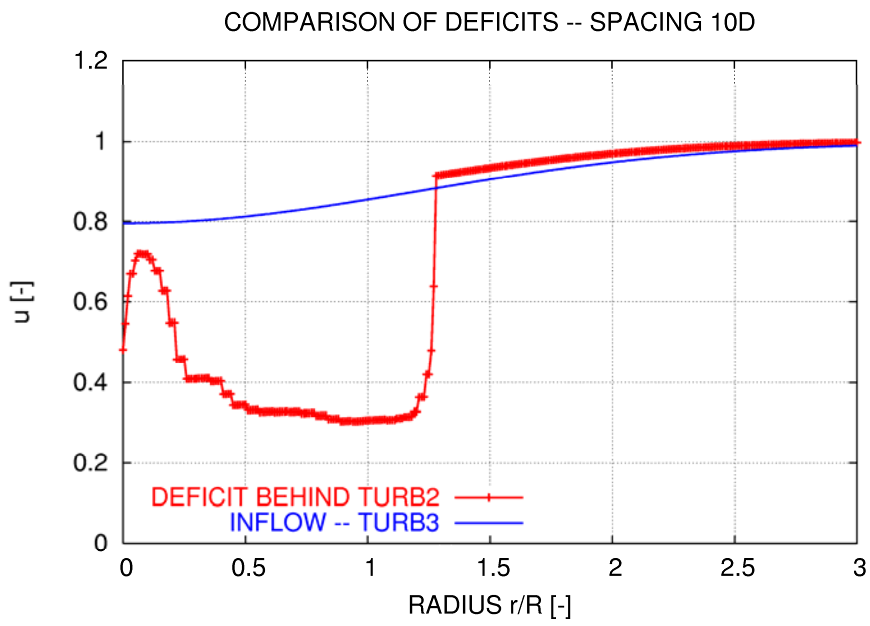
Fig. 9. Relative centre line velocity defect, $(\Delta U/U_{\infty})_0$ as a function of distance downwind from the Näsudden data compared with data from some other sources.

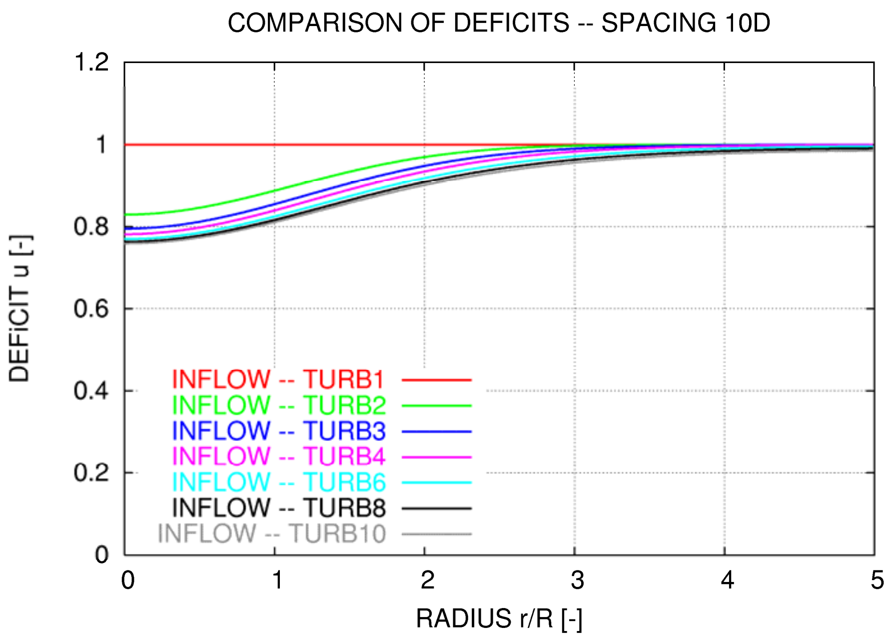
Högström et al. 1988

Comparison with the ACL model – DTU MEK NM80 rotor at 10 m/s – no amb. turbulence

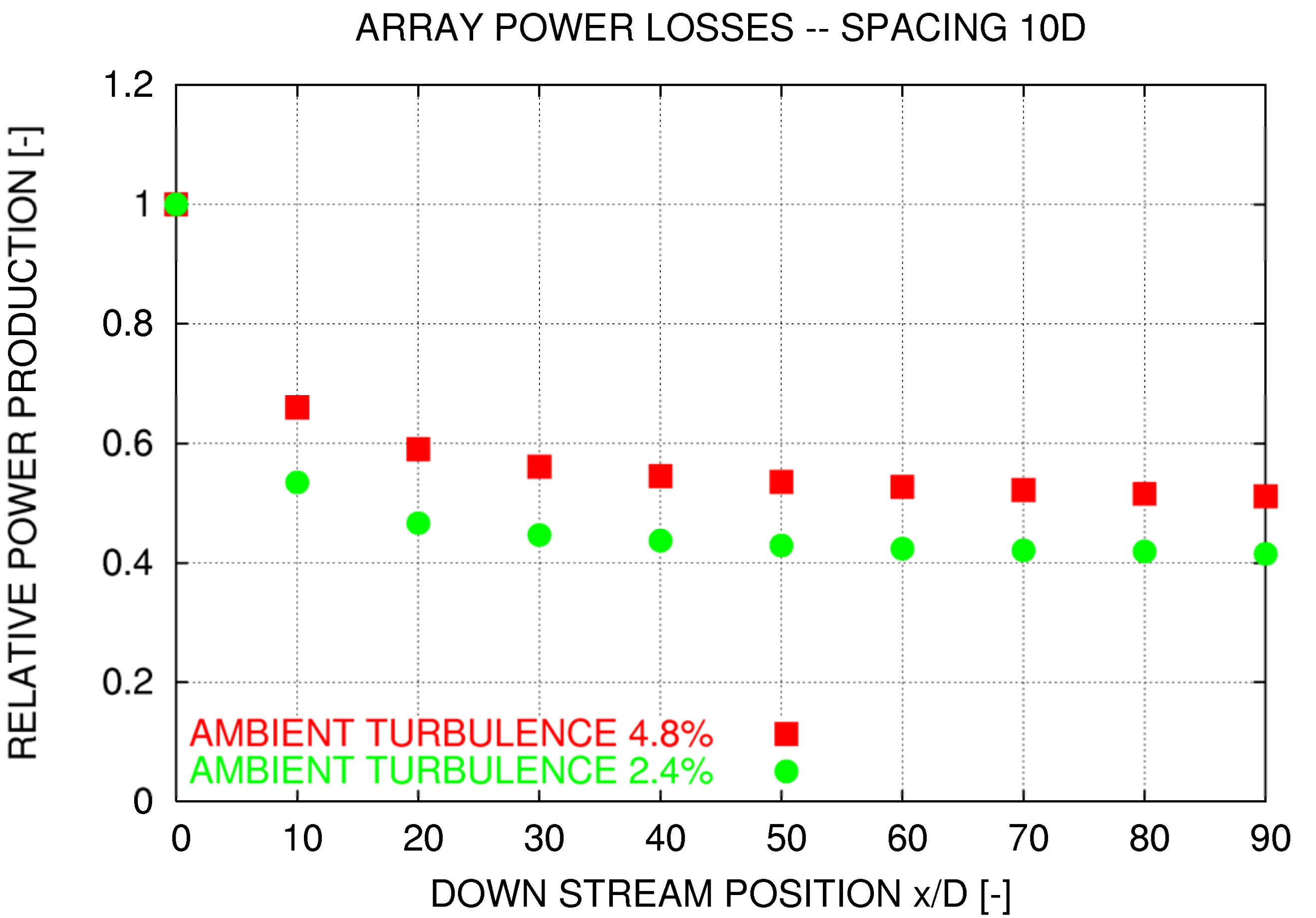


Using the BLE model for computation of power losses of an array of turbines

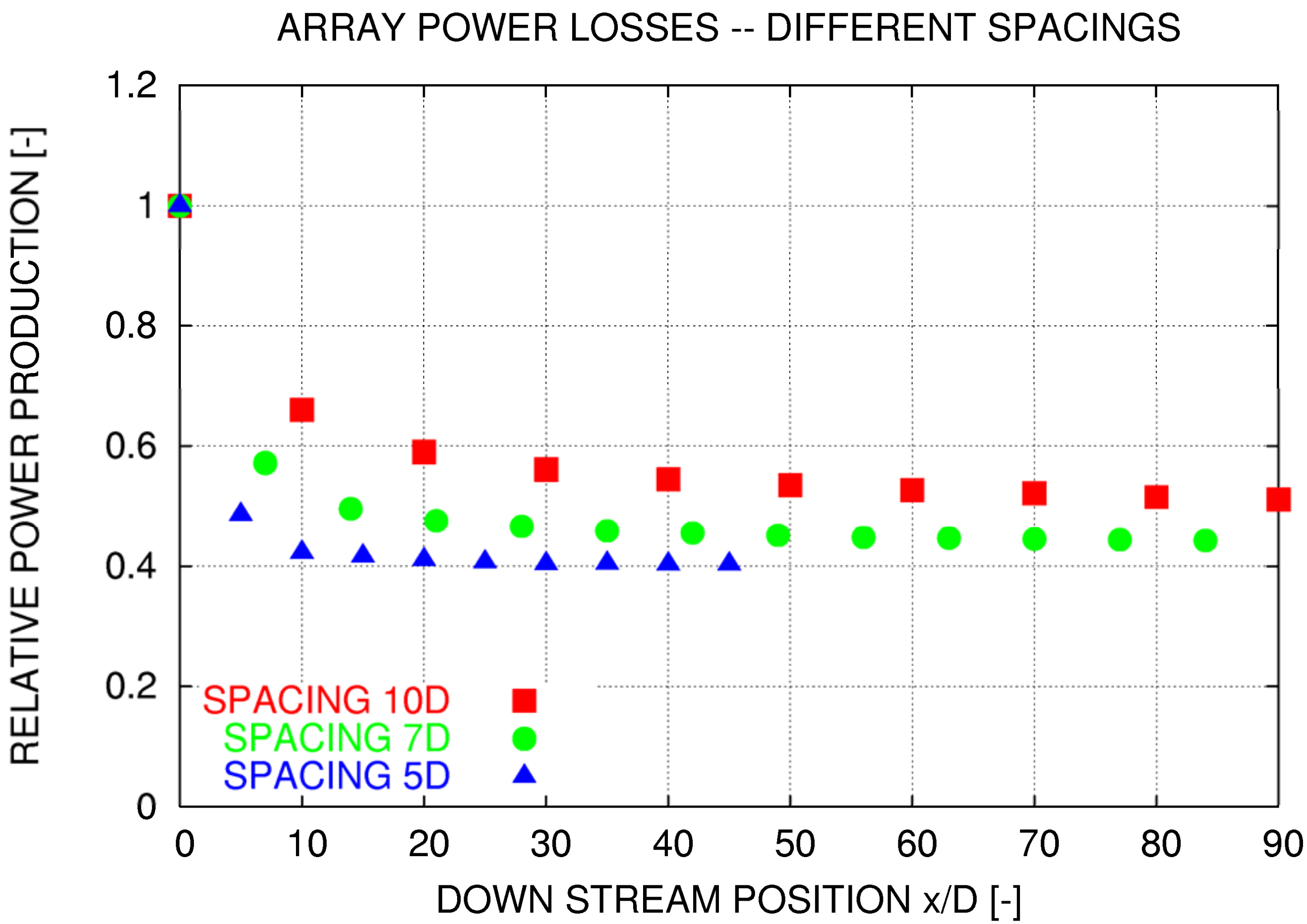




Using the BLE model for computation of power losses of an array of turbines -- NM80 rotor at 10 m/s --



Using the BLE model for computation of power losses of an array of turbines -- NM80 rotor at 10 m/s – ambient turbulence 4.8%



Conclusions and outlook

- an engineering model (BLE) has been devoloped for computation of the velocity deficit behind a turbine
- the influence of ambient turbulence is a key parameter for the development of the velocity deficit as function of downstream position
- the ambient turbulence is thus also one of the key parameters for wind turbine array losses
- further development of the axissymmetric BLE model to a quasy 3D model is investigated